CONTINUATION IN PART

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OLED DISPLAYS WITH FIBER-OPTIC FACEPLATES

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OLED DISPLAYS WITH FIBER-OPTIC FACEPLATES

This is a continuation-in-part of application U.S. Serial No. 10/201,338 filed July 23, 2002.

FIELD OF THE INVENTION

The present invention relates to the use of fiber-optic faceplates with organic light emitting diode (OLED) flat-panel electro-optic devices and optical systems.

BACKGROUND OF THE INVENTION

Organic light emitting diodes (OLED) have many advantages in a flat-panel display device and are useful in optical systems. US Patent No. 6,384,529 issued May 7, 2002 to Tang et al. shows an OLED color display that includes an array of OLED light emitting elements (pixels). Light is emitted from a pixel when a current is passed through an organic material, the frequency of the light depending on the nature of the organic material that is used. The organic materials are placed upon a substrate between electrodes, with an encapsulating cover layer or plate. In such a display, light can be emitted through the substrate (a bottom emitter) or through the encapsulating cover (a top emitter), or both. The emitted light is Lambertian, that is it is emitted equally in every direction. While this is a useful feature in a flat-panel display because the resulting viewing angle is very wide, it is also problematic in that a significant fraction of the light emitted from the OLED materials is internally reflected within the cover or substrate a number of times before being emitted from the display. When such OLED displays are used in optical systems having large numerical apertures such as the head mounted display shown in US 6,181,304, issued Jan 30, 2001 to Robinson et al., or are viewed at large viewing angles, the internal reflections in the substrate or cover plate reduce the sharpness of the display.

There is a need therefore for an improved OLED flat-panel display device with improved sharpness.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing an OLED display device that includes a substrate; an array of OLED elements formed on the substrate, the OLED elements defining an optical cavity for

reducing the angle of emission of light from the OLED elements; an encapsulating cover disposed over the OLED elements; and the display device being viewed through the substrate and/or the cover and wherein the substrate and/or the cover through which the display is viewed is a fiber-optic faceplate, whereby the apparent sharpness of the display device is improved.

ADVANTAGES

The present invention has the advantage that it increases the sharpness of an OLED display device when used in an optical system having a large numerical aperture or viewed from a wide viewing angle.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional partial view of a prior art bottom-emitter OLED display device.

Fig. 2 is a schematic diagram illustrating a prior art heads up display system having a large numerical aperture optical system.

Fig. 3 is a partial cross sectional view of a bottom-emitter OLED display device having a fiber optic face plate according to the present invention.

Fig. 4 is a partial cross sectional view of a top-emitter OLED display device having a fiber optic face plate according to the present invention.

Fig. 5 is a partial cross sectional view of an OLED display device according to the present invention, having one fiber per light emitting element.

Fig. 6 is a partial cross sectional view of an OLED display device according to the present invention, having one fiber for each three-color emitting subpixels.

Fig. 7 is a schematic diagram illustrating an OLED display device having a fiber optic face plate with a curved surface.

Fig. 8 is a graph showing an edge transition in a prior art OLED display device.

Fig. 9 is a graph showing an edge transition in an OLED display device according to the present invention.

Fig. 10 is a partial cross sectional view of a tiled display having tapered fiber optic face plates.

Fig. 11 is a more detailed schematic diagram of a prior art OLED device.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is useful for both top-emitting OLED devices (those that emit light through a cover placed above a substrate on which the OLED is constructed) and bottom-emitting OLED devices (those that emit light through the substrate on which the OLED is constructed).

Referring to Fig. 1, a prior art bottom-emitting OLED device **10** includes a transparent substrate **12**, a first electrode **18**, regions of OLED material forming light emitting pixels **19**, a second electrode **30**, and electrode protection layer **32**, and an encapsulating cover **36** forming a gap **34** above the protection layer **32**. Light is emitted from a pixels **19** and experiences internal reflections in the substrate **12**. As shown in Fig. 2, when employed in a large numerical aperture optical system **60**, such as a head mounted display that is viewed by a human eye **62**, through a large numerical aperture lens **61**, multiple images of the pixel are formed as shown by rays A and B, thereby reducing the apparent sharpness of the display. As used herein , the term large numerical aperture means a system having a numerical aperture greater than 0.25. This sharpness reducing phenomenon is also experienced when such a display is viewed normally at a large angle from the optical axis.

A top emitting device is similar to the bottom emitting device shown in Fig. 1 except that the cover **36**, the second electrode **30**, and the electrode protection layer **32** are transparent. The same problem of sharpness reducing multiple images exists.

In the Figures it is understood that, for simplicity and clarity, not all of the components or layers are shown and that the layers are not drawn to scale. In practice, the OLED layers **19, 30, 32** are very thin compared to cover **36** and substrate **12**.

Referring to Fig. 3, in a bottom emitting display according to the present invention, substrate **12** is a fiber-optic faceplate. A fiber-optic faceplate **12** (or array of light pipes) is composed of many parallel fibers **40**, preferably oriented orthogonal to the surface of the faceplate that transmit light through the

fibers but not between fibers or from one fiber to another. Suitable fiber optic faceplates are commercially available, for example from Schott Corporation, Yonkers, New York. Preferably the diameter of the fibers in the face plate is approximately equal to or smaller than the diameter of the light emitting elements in the display such that at least one fiber transmits light from each pixel in the display. Magnifying fiber optic face plates having tapered fibers can be used to enlarge or reduce the apparent size of the image.

The OLED elements are formed on the surface of the fiber optic face plate in the conventional manner. As shown in Fig. 3, light rays A and C that strike the fiber-optic faceplate cannot propagate horizontally through the substrate (as light does through a conventional glass substrate) and will emerge at or very near to the location at which the light entered the fiber optic face plate, thus eliminating the multiple images and enhancing the sharpness of the display.

Because OLED light emitting elements emit light equally in every direction, not all of which will enter the fiber optic face plate, the performance of the present invention can be enhanced by increasing the amount of light that is emitted orthogonally to the surface of the fiber optic faceplateso that a greater percentage of the light will enter the fibers. If the angle at which light is emitted from the OLED light emitting elements into a fiber is very large compared to the axis of the fiber, many reflections will occur within the fiber before the light leaves the other end of the fiber. At each reflection within the fiber, some light is lost due to incomplete reflection. Light emitted into a fiber from an OLED light emitting elements that is parallel to the axis of the fiber will encounter fewer reflections and consequent losses. Hence, reducing the angle at which light enters a fiber will enhance the amount of light propagated through the fiber.

Increasing the amount of light emitted orthogonally to the surface of the OLED light emitting element will also increase the amount of light taken into the fiber. In conventional practice, up to 80% of the light emitted is lost because it is not transmitted through the cover or substrate of the display. Instead, the light may be emitted in a direction parallel to the face of the fiber optic faceplate and will propagate through the light emissive layers by waveguide action. Therefore, reducing the amount of light emitted parallel to the face of the

faceplate that travels by waveguide through the light emissive layers of organic materials will increase the amount of light that is emitted usefully into the fibers of the fiber optic faceplate.

A reduced angle of emission from the OLED light emitting elements can be achieved by forming an optical cavity between the electrodes providing current to the OLED light emitting elements. Electrodes can be made of highly reflective, thin layers of metal. By making the electrode opposite to the direction of emission completely reflective and the electrode though which light passes partially reflective, an optical cavity can be formed. The optical cavity is tuned to the preferred frequency at which light is to be emitted by carefully depositing layers of the required thickness. The light within the cavity will form a standing wave pattern at the desired frequency and with a reduced angle of emission. Optical cavities of this type are known in the art, as are suitable metallic electrodes, for example silver. For example, see US Patent application 20030184892 published 20031002, by Lu et al., which is incorporated herein by reference It is also possible to use optical cavity designs that produce coherent laser light as described in published US patent application No. US20030161368 published 20030828 by Kahen et al. and US20020171088 published 20021121 by Kahen et al. which are incorporated herein by reference. Applicants have demonstrated both incoherent and coherent OLED light emission having a reduced angle of emission that is suitable for the present invention.

In a bottom-emitting display, the electrode **18** must be partially reflective while the electrode **30** can be totally reflective. In a top-emitter configuration, the electrode **18** is reflective while the electrode **30** is partially reflective.

Applicants have demonstrated the use of an optical cavity for the enhancement of light emission from an OLED structure with both white-light emitting materials and for red, green, and blue light-emitting materials. In all cases, the use of a properly sized cavity with the use of a thin layer of silver or silver compounds as the partially reflective electrode and a thicker layer of either silver or aluminum or compounds of aluminum or silver as the reflective electrode results in greater light emission orthogonal to the electrodes and with a narrower spectrum. Partially reflective electrodes may also consist of a two-layer structure

in which a first layer is a transparent conductor and a second layer is a partially reflective mirror.

In conventional practice, the use of an optical cavity in a display application has the significant drawback of a color change as the display is viewed at angles other than the orthogonal. In the present invention, no such disadvantage is seen since all of the emitted light that passes into the fiber will be reflected several times and mixed as it passes through the fiber. When the light emerges from the fiber it will be mixed and have no such dependency on viewing angle.

In an alternative embodiment of the present invention, a fiber-optic faceplate is used as the cover **36** of a top-emitting OLED display device. Referring to Fig. 4, the layers of the OLED device are formed conventionally on a substrate **12**, and the device is encapsulated using the fiber-optic face plate as an encapsulating cover. In operation, the light emitted by the OLED pixels **19** traverses the gap **34** and is coupled into the fiber-optic cover from which it is emitted as described above for a bottom-emitting OLED device. Preferably, the gap **34** is filled with a transparent material having an index of refraction matching the fiber optic face.

Referring to Fig. 5, the fiber-optic faceplate used as a cover **36** for a top emitter OLED display has one fiber or light pipe **40** for each light emitting pixel element **19**. Referring to Fig. 6, the display is a color OLED display wherein each light emitting pixel includes color subpixels **19R**, **19G** and **19B**, for emitting red, green and blue light respectively. One fiber or light pipe **40** is employed for the entire three-color pixel. Alternatively, one fiber for each subpixel may be employed.

Referring to Fig. 7, according to one embodiment of the present invention, the fiber-optic faceplate **36** has one flat face **41** arranged adjacent to the OLED light emitters **19** and a second face **42** that is not parallel to face **41**, (for example having a spherical surface as shown in the Fig. 7). This arrangement can be used in either a top or bottom emitting OLED display device. For example, a spherical wave front can be efficiently created by utilizing a fiber plate with one flat side and the other side having a spherical surface as shown in Fig. 7. The

spherical surface can be, either concave or convex depending on the application in the optical system.

Applicants have compared the present invention with the prior art by fabricating identical bottom-emitter OLED display devices on a glass substrate and on a fiber-optic faceplate. A scan of a transition between a row of light and dark pixels on the device formed on a conventional glass substrate using a microscope having a large numerical aperture resulted in a transition having the form shown in Fig. 8. A microscopic scan of a transition between a row of light and dark pixels on the device formed on the fiber optic face plate resulted in a transition having the form shown in Fig. 9. As can be seen by comparing the graphs of Figs. 8 and 9, the transition measured from the display having the fiber optic face plate is considerably sharper. Tests were performed with the microscope objective oriented both orthogonally to the surface of the device and at an angle to the surface of the devices and similar results were obtained.

Referring to Fig. 10, display devices having tapered fiber optic face plates **38** can be assembled into a tiled display mounted on a support **11**. The tapered face plate has a smaller light receiving surface adjacent the light emitting elements and a larger light emitting surface. The tapered fiber optic face plates **38** serve a dual function of improving the sharpness of the display, as discussed above, while facilitating the tiling of the display. The arrays of light emitting elements **19** can be spaced apart from each other on the support **11**, while the edges of the fiber optic face plates are abutted to provide a seamless appearance to the tiled display.

The invention is preferably employed in a device that includes Organic Light Emitting Diodes (OLEDs) which are composed of small molecule or polymeric OLEDs as disclosed in but not limited to U. S. Patent No. 4,769,292, issued September 6, 1988 to Tang et al., entitled "Electroluminescent Device with Modified Thin Film Luminescent Zone" and U. S. Patent No. 5,061,569, issued October 29, 1991 to VanSlyke et al., entitled "Electroluminescent Device with Organic Electroluminescent Medium. Many combinations and variations of organic light emitting devices can be used to fabricate such a device.

General device architecture

The present invention can be employed in most OLED device configurations. These include very simple structures comprising a single anode and cathode to more complex devices, such as passive matrix displays comprised of orthogonal arrays of anodes and cathodes to form pixels, and active-matrix displays where each pixel is controlled independently, for example, with thin film transistors (TFTs).

There are numerous configurations of the organic layers wherein the present invention can be successfully practiced. A typical structure is shown in Fig. 11 and is comprised of a substrate **101**, an anode **103**, a hole-injecting layer **105**, a hole-transporting layer **107**, a light-emitting layer **109**, an electron-transporting layer **111**, and a cathode **113**. These layers are described in detail below. Note that the substrate may alternatively be located adjacent to the cathode, or the substrate may actually constitute the anode or cathode. The organic layers between the anode and cathode are conveniently referred to as the organic EL element. The total combined thickness of the organic layers is preferably less than 500 nm.

The anode and cathode of the OLED are connected to a voltage/current source **250** through electrical conductors **260**. The OLED is operated by applying a potential between the anode and cathode such that the anode is at a more positive potential than the cathode. Holes are injected into the organic EL element from the anode and electrons are injected into the organic EL element at the anode. Enhanced device stability can sometimes be achieved when the OLED is operated in an AC mode where, for some time period in the cycle, the potential bias is reversed and no current flows. An example of an AC driven OLED is described in US 5,552,678.

Substrate

The OLED device of this invention is typically provided over a supporting substrate where either the cathode or anode can be in contact with the substrate. The electrode in contact with the substrate is conveniently referred to as the bottom electrode. Conventionally, the bottom electrode is the anode, but this invention is not limited to that configuration. The substrate can either be light

transmissive or opaque, depending on the intended direction of light emission. The light transmissive property is desirable for viewing the EL emission through the substrate. Transparent glass or plastic is commonly employed in such cases. For applications where the EL emission is viewed through the top electrode, the transmissive characteristic of the bottom support is immaterial, and therefore can be light transmissive, light absorbing or light reflective. Substrates for use in this case include, but are not limited to, glass, plastic, semiconductor materials, silicon, ceramics, and circuit board materials. Of course it is necessary to provide in these device configurations a light-transparent top electrode.

Anode

When EL emission is viewed through anode **103**, the anode should be transparent or substantially transparent to the emission of interest. Common transparent anode materials used in this invention are indium-tin oxide (ITO), indium-zinc oxide (IZO) and tin oxide, but other metal oxides can work including, but not limited to, aluminum- or indium-doped zinc oxide, magnesium-indium oxide, and nickel-tungsten oxide. In addition to these oxides, metal nitrides, such as gallium nitride, and metal selenides, such as zinc selenide, and metal sulfides, such as zinc sulfide, can be used as the anode. For applications where EL emission is viewed only through the cathode electrode, the transmissive characteristics of anode are immaterial and any conductive material can be used, transparent, opaque or reflective. Example conductors for this application include, but are not limited to, gold, iridium, molybdenum, palladium, and platinum. Typical anode materials, transmissive or otherwise, have a work function of 4.1 eV or greater. Desired anode materials are commonly deposited by any suitable means such as evaporation, sputtering, chemical vapor deposition, or electrochemical means. Anodes can be patterned using well-known photolithographic processes. Optionally, anodes may be polished prior to application of other layers to reduce surface roughness so as to minimize shorts or enhance reflectivity.

Hole-Injecting Layer (HIL)

While not always necessary, it is often useful to provide a hole-injecting layer **105** between anode **103** and hole-transporting layer **107**. The hole-

injecting material can serve to improve the film formation property of subsequent organic layers and to facilitate injection of holes into the hole-transporting layer. Suitable materials for use in the hole-injecting layer include, but are not limited to, porphyrinic compounds as described in US 4,720,432, plasma-deposited fluorocarbon polymers as described in US 6,208,075, and some aromatic amines, for example, m-MTDATA (4,4',4"-tris[(3-methylphenyl)phenylamino]triphenylamine). Alternative hole-injecting materials reportedly useful in organic EL devices are described in EP 0 891 121 A1 and EP 1 029 909 A1.

Hole-Transporting Layer (HTL)

The hole-transporting layer **107** contains at least one hole-transporting compound such as an aromatic tertiary amine, where the latter is understood to be a compound containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine, diarylamine, triarylamine, or a polymeric arylamine. Exemplary monomeric triarylamines are illustrated by Klupfel et al. U.S. Patent No. 3,180,730. Other suitable triarylamines substituted with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are disclosed by Brantley et al U.S. Patent Nos. 3,567,450 and 3,658,520.

A more preferred class of aromatic tertiary amines are those which include at least two aromatic tertiary amine moieties as described in U.S. Patent Nos. 4,720,432 and 5,061,569. The hole-transporting layer can be formed of a single or a mixture of aromatic tertiary amine compounds. Illustrative of useful aromatic tertiary amines are the following:

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane

1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane

4,4'-Bis(diphenylamino)quadriphenyl

Bis(4-dimethylamino-2-methylphenyl)-phenylmethane

N,N,N-Tri(*p*-tolyl)amine

4-(di-p-tolylamino)-4'-[4(di-*p*-tolylamino)-styryl]stilbene

N,N,N',N'-Tetra-*p*-tolyl-4-4'-diaminobiphenyl

N,N,N',N'-Tetraphenyl-4,4'-diaminobiphenyl
N,N,N',N'-tetra-1-naphthyl-4,4'-diaminobiphenyl
N,N,N',N'-tetra-2-naphthyl-4,4'-diaminobiphenyl
N-Phenylcarbazole
4,4'-Bis[N-(1-naphthyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]biphenyl
4,4"-Bis[N-(1-naphthyl)-N-phenylamino]p-terphenyl
4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(3-acenaphthenyl)-N-phenylamino]biphenyl
1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene
4,4'-Bis[N-(9-anthryl)-N-phenylamino]biphenyl
4,4"-Bis[N-(1-anthryl)-N-phenylamino]-*p*-terphenyl
4,4'-Bis[N-(2-phenanthryl)-N-phenylamino]biphenyl
4,4'-Bis[N-(8-fluoranthenyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(2-pyrenyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(2-naphthacenyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(2-perylenyl)-N-phenylamino]biphenyl
4,4'-Bis[N-(1-coronenyl)-N-phenylamino]biphenyl
2,6-Bis(di-*p*-tolylamino)naphthalene
2,6-Bis[di-(1-naphthyl)amino]naphthalene
2,6-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]naphthalene
N,N,N',N'-Tetra(2-naphthyl)-4,4"-diamino-*p*-terphenyl
4,4'-Bis{N-phenyl-N-[4-(1-naphthyl)-phenyl]amino}biphenyl
4,4'-Bis[N-phenyl-N-(2-pyrenyl)amino]biphenyl
2,6-Bis[N,N-di(2-naphthyl)amine]fluorene
1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene
4,4',4"-tris[(3-methylphenyl)phenylamino]triphenylamine

Another class of useful hole-transporting materials includes polycyclic aromatic compounds as described in EP 1 009 041. Tertiary aromatic amines with more than two amine groups may be used including oligomeric materials. In addition, polymeric hole-transporting materials can be used such as

poly(N-vinylcarbazole) (PVK), polythiophenes, polypyrrole, polyaniline, and copolymers such as poly(3,4-ethylenedioxythiophene) / poly(4-styrenesulfonate) also called PEDOT/PSS.

Light-Emitting Layer (LEL)

As more fully described in U.S. Patent Nos. 4,769,292 and 5,935,721, the light-emitting layer (LEL) **109** of the organic EL element includes a luminescent or fluorescent material where electroluminescence is produced as a result of electron-hole pair recombination in this region. The light-emitting layer can be comprised of a single material, but more commonly consists of a host material doped with a guest compound or compounds where light emission comes primarily from the dopant and can be of any color. The host materials in the light-emitting layer can be an electron-transporting material, as defined below, a hole-transporting material, as defined above, or another material or combination of materials that support hole-electron recombination. The dopant is usually chosen from highly fluorescent dyes, but phosphorescent compounds, e.g., transition metal complexes as described in WO 98/55561, WO 00/18851, WO 00/57676, and WO 00/70655 are also useful. Dopants are typically coated as 0.01 to 10 % by weight into the host material. Polymeric materials such as polyfluorenes and polyvinylarylenes (e.g., poly(p-phenylenevinylene), PPV) can also be used as the host material. In this case, small molecule dopants can be molecularly dispersed into the polymeric host, or the dopant could be added by copolymerizing a minor constituent into the host polymer.

An important relationship for choosing a dye as a dopant is a comparison of the bandgap potential which is defined as the energy difference between the highest occupied molecular orbital and the lowest unoccupied molecular orbital of the molecule. For efficient energy transfer from the host to the dopant molecule, a necessary condition is that the band gap of the dopant is smaller than that of the host material. For phosphorescent emitters it is also important that the host triplet energy level of the host be high enough to enable energy transfer from host to dopant.

Host and emitting molecules known to be of use include, but are not limited to, those disclosed in U.S. Patent Nos. 4,768,292; 5,141,671;

5,150,006; 5,151,629; 5,405,709; 5,484,922; 5,593,788; 5,645,948; 5,683,823; 5,755,999; 5,928,802; 5,935,720; 5,935,721; and 6,020,078.

Metal complexes of 8-hydroxyquinoline (oxine) and similar derivatives constitute one class of useful host compounds capable of supporting electroluminescence. Illustrative of useful chelated oxinoid compounds are the following:

CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]

CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]

CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)

CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)-□-oxo-bis(2-methyl-8-quinolinolato) aluminum(III)

CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]

CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato) aluminum(III)]

CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]

CO-8: Gallium oxine [alias, tris(8-quinolinolato)gallium(III)]

CO-9: Zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)]

Other classes of useful host materials include, but are not limited to: derivatives of anthracene, such as 9,10-di-(2-naphthyl)anthracene and derivatives thereof as described in US 5,935,721, distyrylarylene derivatives as described in US 5,121,029, and benzazole derivatives, for example, 2, 2', 2"-(1,3,5-phenylene)tris[1-phenyl-1H-benzimidazole]. Carbazole derivatives are particularly useful hosts for phosphorescent emitters.

Useful fluorescent dopants include, but are not limited to, derivatives of anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, and quinacridone, dicyanomethylenepyran compounds, thiopyran compounds, polymethine compounds, pyrilium and thiapyrilium compounds, fluorene derivatives, periflanthene derivatives, indenoperylene derivatives, bis(azinyl)amine boron compounds, bis(azinyl)methane compounds, and carbostyryl compounds.

Electron-Transporting Layer (ETL)

Preferred thin film-forming materials for use in forming the electron-transporting layer **111** of the organic EL elements of this invention are metal chelated oxinoid compounds, including chelates of oxine itself (also commonly referred to as 8-quinolinol or 8-hydroxyquinoline). Such compounds help to inject and transport electrons, exhibit high levels of performance, and are readily fabricated in the form of thin films. Exemplary oxinoid compounds were listed previously.

Other electron-transporting materials include various butadiene derivatives as disclosed in U.S. Patent No. 4,356,429 and various heterocyclic optical brighteners as described in U.S. Patent No. 4,539,507. Benzazoles and triazines are also useful electron-transporting materials.

Cathode

When light emission is viewed solely through the anode, the cathode **113** used in this invention can be comprised of nearly any conductive material. Desirable materials have good film-forming properties to ensure good contact with the underlying organic layer, promote electron injection at low voltage, and have good stability. Useful cathode materials often contain a low work function metal (< 4.0 eV) or metal alloy. One preferred cathode material is comprised of a Mg:Ag alloy wherein the percentage of silver is in the range of 1 to 20 %, as described in U.S. Patent No. 4,885,221. Another suitable class of cathode materials includes bilayers comprising a thin electron-injection layer (EIL) in contact with the organic layer (e.g., ETL) which is capped with a thicker layer of a conductive metal. Here, the EIL preferably includes a low work function metal or metal salt, and if so, the thicker capping layer does not need to

have a low work function. One such cathode is comprised of a thin layer of LiF followed by a thicker layer of Al as described in U.S. Patent No. 5,677,572. Other useful cathode material sets include, but are not limited to, those disclosed in U.S. Patent Nos. 5,059,861; 5,059,862, and 6,140,763.

When light emission is viewed through the cathode, the cathode must be transparent or nearly transparent. For such applications, metals must be thin or one must use transparent conductive oxides, or a combination of these materials. Optically transparent cathodes have been described in more detail in US 4,885,211, US 5,247,190, JP 3,234,963, US 5,703,436, US 5,608,287, US 5,837,391, US 5,677,572, US 5,776,622, US 5,776,623, US 5,714,838, US 5,969,474, US 5,739,545, US 5,981,306, US 6,137,223, US 6,140,763, US 6,172,459, EP 1 076 368, US 6,278,236, and US 6,284,393. Cathode materials are typically deposited by evaporation, sputtering, or chemical vapor deposition. When needed, patterning can be achieved through many well known methods including, but not limited to, through-mask deposition, integral shadow masking, for example, as described in US 5,276,380 and EP 0 732 868, laser ablation, and selective chemical vapor deposition.

Other Common Organic Layers and Device Architecture

In some instances, layers **109** and **111** can optionally be collapsed into a single layer that serves the function of supporting both light emission and electron transportation. It also known in the art that emitting dopants may be added to the hole-transporting layer, which may serve as a host. Multiple dopants may be added to one or more layers in order to create a white-emitting OLED, for example, by combining blue- and yellow-emitting materials, cyan- and red-emitting materials, or red-, green-, and blue-emitting materials. White-emitting devices are described, for example, in EP 1 187 235, US 20020025419, EP 1 182 244, US 5,683,823, US 5,503,910, US 5,405,709, and US 5,283,182.

Additional layers such as electron or hole-blocking layers as taught in the art may be employed in devices of this invention. Hole-blocking layers are commonly used to improve efficiency of phosphorescent emitter devices, for example, as in US 20020015859.

This invention may be used in so-called stacked device architecture, for example, as taught in US 5,703,436 and US 6,337,492.

Deposition of organic layers

The organic materials mentioned above are suitably deposited through a vapor-phase method such as sublimation, but can be deposited from a fluid, for example, from a solvent with an optional binder to improve film formation. If the material is a polymer, solvent deposition is useful but other methods can be used, such as sputtering or thermal transfer from a donor sheet. The material to be deposited by sublimation can be vaporized from a sublimator "boat" often comprised of a tantalum material, e.g., as described in U.S. Patent No. 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow masks, integral shadow masks (U.S. Patent No. 5,294,870), spatially-defined thermal dye transfer from a donor sheet (U.S. Patent Nos. 5,688,551, 5,851,709 and 6,066,357) and inkjet method (U.S. Patent No. 6,066,357).

Encapsulation

Most OLED devices are sensitive to moisture or oxygen, or both, so they are commonly sealed in an inert atmosphere such as nitrogen or argon, along with a desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates. Methods for encapsulation and desiccation include, but are not limited to, those described in U.S. Patent No. 6,226,890. In addition, barrier layers such as SiOx, Teflon, and alternating inorganic/polymeric layers are known in the art for encapsulation.

Optical Optimization

OLED devices of this invention can employ various well-known optical effects in order to enhance its properties if desired. This includes optimizing layer thicknesses to yield maximum light transmission, providing dielectric mirror structures, replacing reflective electrodes with light-absorbing electrodes, providing anti glare or anti-reflection coatings over the display,

providing a polarizing medium over the display, or providing colored, neutral density, or color conversion filters over the display. Filters, polarizers, and anti-glare or anti-reflection coatings may be specifically provided over the cover or as part of the cover.

The entire contents of the patents and other publications referred to in this specification are incorporated herein by reference.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	OLED display device
11	support
12	substrate
18	first electrode
19	OLED material
19R,G,B	red, green and blue emitting OLED material
30	second electrode
32	electrode protection layer
34	gap
36	encapsulating cover
38	tapered fiber optic face plate
40	fiber optic element
41	planar surface
42	curved surface
60	optical system
61	lens
62	viewer's eye
101	substrate
103	anode
105	hole injecting layer
107	hole transporting layer
109	light emitting layer
111	electron transporting layer
113	cathode
250	current source
260	electrical conductors